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Absolute hardness of phenanthrene doped anthracene single crystals by Knoop indentation technique

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Abstract : The absolute hardness value of anthracene doped with phenanthrene using Knoop hardness technique has been obtained The absolute hardness is defined as the hardness which is not load dependent The results obtained by graphical analysis compare well with the calculated results, within experimental error The present note reports the results obtained, using the method utilizing the extrapolation function The higher absolute hardness of the phenanthrene doped anthracene is due to the molecular hindrance to slip

Keywords Absolute hardness, Knoop indentation, doped anthracene

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It is a well known fact that the physical and chemical properties of materials are effected by the addition of impurities. This depends on how the impurities enter the lattice. It has been reported [1] that the doping of anthracene by different compounds does not alter the slip systems. The addition of impurities changes the activeness of the slip systems [2]. The present communication compares the absolute hardness of phenanthrene doped anthracene crystals with that of pure anthracene crystals [3].

Single crystal cleavages of phenanthrene doped anthracene were indented on the (001) planes using the Knoop indenter. A large number of indentations were made at each load and the hardness value obtained using the following relation :

$$\text{Knoop hardness } H_k = 0.14 \times P/L^2 \text{ (MPa)}, \quad (1)$$

where P is the applied load in g and L is the mean diagonal length in micron. The indentation time of 10 s was kept constant as this time was adequate to minimize the vibration effects on the results. The crystal size was much larger than the indentation size, thus eliminating the boundary effects on the results. The distance between the indents was five times the size of the largest indentation mark. The crystal thickness was relatively large such that the indenter did not sense the lower surface [4]. A large number of crystals were indented.

The reciprocal indentation length was plotted against hardness and a best fit straight line was drawn from the points using the Harvard graphics software [5]. This method utilizes an extrapolation function to determine the true hardness [6] and is as follows :

Let

P = applied load,

L_0 = observed length of indentation,

L_t = true length of indentation under applied load,

$\Delta L = L_t - L_0$ = length correction of indentation,

C = a constant,

H_0 = observed hardness,

H_t = true hardness.

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Then

$$H_0 = P/(C\,L_0^2) \text{ and } H_t = P/(C\,L_t^2).$$

Therefore, $H_0\,L_0^2 = H_t\,L_t^2$. (2)

But $L_t = \Delta L + L_0$,

hence, $H_0\,L_0^2 = H_t\,(\Delta L + L_0)^2$.

Therefore, $H_0 = H_t\,(1 + \Delta L / L_0)^2$. (3)

The precision of the hardness measurements is not better than 1% so the quadratic term $(\Delta L / L_0)^2$ is neglected. If $(\Delta L / L_0) < 0.1$ then

$$H_0 = H_t + 2\,\Delta L\,H_t\,(1/L_0). \quad (4)$$

The correction term ΔL has been interpreted as being due to either elastic recovery [7] or optical resolution [8]. In either case, if ΔL is a constant and if the true hardness H_t is independent of indentation size, then according to eq. (4), a plot of H_0 *versus* $1/L_0$ gives a straight line with an ordinate intercept H_t and a slope (2 $\Delta L\ H_t$).

The relation (4) was used to calculate the absolute hardness where H_t = true hardness values obtained from Figures (1-2).

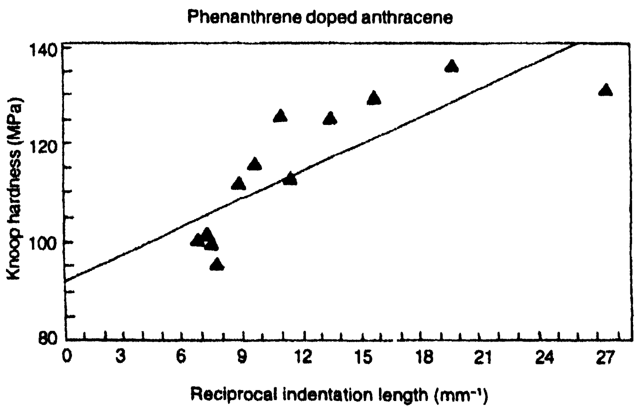

Figure 1. Reciprocal indentation diagonal length *versus* hardness for phenanthrene doped anthracene.

Table 1 presents the graphical and calculated absolute hardness values.

Table 1. The true hardness values obtained from graphical and mathematical analysis.

Crystal	Knoop hardness (graphical) (MPa)	Knoop hardness (calculated) (MPa)
Anthracene	50.10	49.55
Phenanthrene doped anthracene	92.00	90.64

Figure 1 depicts the plot of reciprocal indentation length *versus* hardness for phenanthrene doped anthracene single crystals.

Figure 2 depicts the plot of reciprocal indentation length *versus* hardness for pure anthracene single crystals.

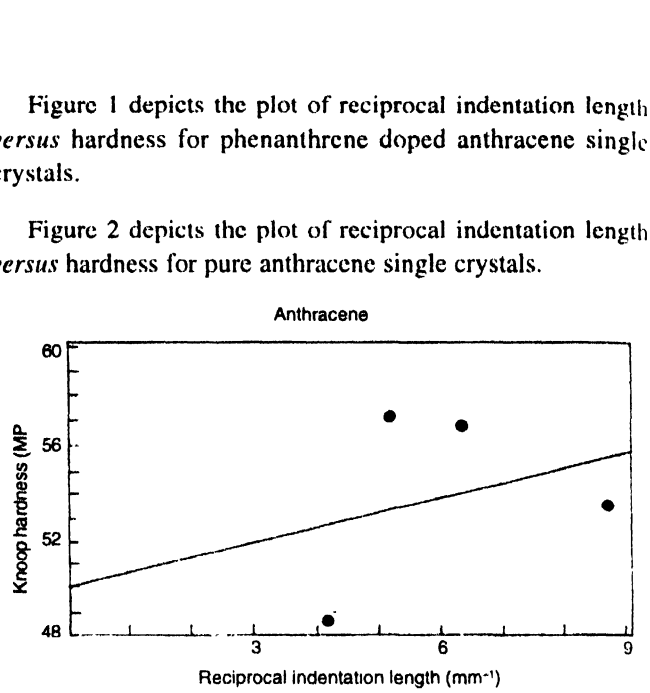

Figure 2. Reciprocal indentation diagonal length *versus* hardness for pure anthracene.

The absolute hardness values H_t obtained from the graphs (Figures 1, 2) are used to find the length correction terms ΔL. The calculated true hardness values are found using the relations :

$$H_t\ (\text{Knoop}) = 0.14 \times P / (\Delta L + L_0)^2 \ (\text{MPa}). \quad (5)$$

Table 1 presents the graphical and calculated absolute hardness values for both crystals. These values compare well The absolute hardness value for pure anthracene is 49.55 MPa whereas that of phenanthrene doped anthracene is 90.64 MPa Phenanthrene goes in substitutionally into the anthracene lattice. The shape of the phenanthrene molecule is not similar to the anthracene molecule, both being made up of three benzene rings and having the formula $C_{14}H_{10}$. The molecular shape causes a hindrance in the motion of the slip planes giving rise to a higher absolute hardness value for phenanthrene doped anthracene single crystals.

The absolute hardness value of phenanthrene doped anthracene obtained by the utilization of the extrapolation function is 90.64 MPa and is higher than that of pure anthracene which is 49.55 MPa. This increase in absolute hardness value is due to the molecular shape of the phenanthrene molecule which goes in substitutionally into the anthracene lattice and causes a hindrance to the motion of the slip planes.

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